Estimation of Ephemeral Streamflow Duration Using Temperature Methods in the Upper San Pedro River Basin, Arizona

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Abstract

A new method for interpreting the onset and cessation of streamflow in ephemeral streams using temperature sensor data is being utilized in the Sierra Vista subwatershed of the Upper San Pedro River Basin. Previous detection methods involved a moving standard deviation window technique and visual inspection of thermographs. The method presented here uses a rapid temperature drop greater than a designated threshold value to indicate flow onset and the following low temperature inflection point to indicate flow cessation. The temperature-drop threshold value is dependent on the mean thermal wave amplitude preceding the temperature drop. The amplitude is a function of the sensor burial depth and the antecedent soil water content in the sediments. The temperature-drop – low-temperature inflection point method was tested using a sensor buried 30 to 33 centimeters below the streambed surface and 10 meters downstream from a U.S. Geological Survey streamflow-gaging station in an ephemeral wash. Using the optimum temperature-drop thresholds of 0.25°C and 0.30°C, the method correctly identified 85 percent of all flows and had an 8 percent false positive detection rate. The average timing error of flow onset was 37 minutes with a standard deviation of 110 minutes, and the average timing error of flow cessation was 4 minutes with a standard deviation of 232 minutes.

Keywords: ephemeral flow, flow duration, temperature, thermograph

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Introduction

Identification of intermittent and ephemeral streamflow using temperature sensors has been accomplished by visual inspection of thermographs (Constantz et al. 2001) and by using statistical techniques, particularly standard deviation windows centered on the time of flow events (Blasch et al. 2002, Lawler 2002). Both methods are based on the premise that the presence of streamflow in an ephemeral channel reduces the amplitude of the diurnal thermal wave propagating through the sediments.

Using the visual inspection method, periods of flow are characterized by those sections of the thermograph where the amplitude of the diurnal temperature signal is visibly dampened (Constantz 2001). When the in-stream temperature data are compared graphically to temperature data from a nearby site out of streamflow (benchmark thermograph) where little dampening has occurred, a flow signal is readily identifiable. In addition, during periods of flow there is generally a change in the shape of the residual wave form (stream thermograph minus benchmark thermograph).

The standard deviation method uses the standard deviation of the temperature signal over a moving window of 1 to 12 hours (Blasch et al. 2002) or a static window of 24 hours (Lawler 2002), and those standard deviation values that exceed a specified threshold value are interpreted as the onset and cessation of flow. Using an optimized, 6-hour, moving standard deviation window (0 percent false positive and 0 percent false negative detections) on data gathered at Rillito Creek in Tucson, Arizona, Blasch et al. (2002) found the average timing error was 95 minutes at flow onset and 310 minutes at flow cessation. Using a static, 24-hour standard deviation window with different summer and winter thresholds, Lawler (2002) was able to correctly identify 78 percent and 80 percent, respectively, of the periods of flow of the San Pedro River near Palominas, Arizona. This improved to 80 percent for both summer and winter periods using a daily amplitude threshold.

Methods

This study uses a new technique for the identification of flow onset and cessation that is suited for the small drainages and short ephemeral flows ($t < 24$ hours) that are common to most tributary stream channels in the study area—the Sierra Vista subwatershed of the Upper San Pedro River Basin in southeastern Arizona. In a previously dry streambed, the onset of flow can be identified by a sharp drop in temperature of 0.20°C or more over 15 minutes (Figure 1). The minimum temperature drop required to identify flow onset will vary with the mean amplitude of the thermal wave. The thermal wave amplitude is a function of sensor burial depth (deeper burials will show a smaller temperature drop at flow onset) and antecedent soil water content in the sediments surrounding the sensor (the greater the volume of antecedent water the smaller the temperature drop at flow onset). Flow cessation is identified by the low-temperature inflection point that follows the sharp temperature drop (Figure 1).

The utility of this method for determining streamflow was tested over the summer of 2002 using a TidbiT© temperature sensor that had a precision of 0.1°C buried 10 meters downstream from a USGS streamflow-gaging station in Greenbush Draw. Greenbush Draw is an ephemeral tributary of the San Pedro River tributary at the upper end of the Sierra Vista subwatershed. On May 2, 2002 the sensor was buried approximately 33 centimeters below the streambed surface, under 25-27 centimeters of clay with some sand, and 6-8 centimeters of sand with some clay. Thirteen ephemeral flow events were recorded at the Greenbush Draw gaging station during the summer of 2002, and the sensor was recovered approximately 30 centimeters below the streambed surface on September 17, 2002. The temperature sensor recorded every 15 minutes.

The temperature-drop – low-temperature inflection point method was subsequently applied to temperature data previously gathered from other ephemeral streams in the Sierra Vista subwatershed (Figure 2). Results of one such application—the Woodcutters Canyon drainage on the west side of the subwatershed—are presented below and in Table 2.

Results

The optimal temperature-drop threshold to be used for flow detection is selected on the basis of maximizing correct flow detection while minimizing false negative and false positive detections of flows, and minimizing the time between predicted and actual flow onset and cessation. A false negative detection is one in which flow occurs but is not detected. A false positive detection is the reverse; flow does not occur, but flow is indicated using the temperature-drop – low temperature-inflection point method. For the purposes of this study, streamflow-gaging station data are used to determine when flow occurs.

The data are compiled in Table 1, where time of temperature drop, time of low-temperature inflection point, and elapsed time between the two are compared to onset of flow, cessation of flow, and duration of flow, respectively. Temperature-drop thresholds tested ranged from 0.20°C to 1.0°C. Using temperature-drop thresholds of 0.20°C, 0.25°C and 0.30°C, 11 of the 13 flows (85 percent) were correctly identified (15 percent false negative detection). The percent false positive detections for the 0.20°C temperature drop threshold is 69 percent. This decreases to 8 percent (1 false detection out of 12 flows detected) for both the 0.25°C and 0.30°C thresholds. Thus, for purposes of flow detection, the 0.25°C and 0.30°C thresholds are optimum. The mean difference between the time of actual flow onset and the time of temperature drop is low (37 minutes) as is the standard deviation (less than 2 hours). The mean difference between the time of flow cessation and the time of the low-temperature inflection point is very low (4 minutes), but the standard deviation is high (nearly 4 hours).

Field application

Table 2 presents the results of this interpretive technique applied to Woodcutters Wash on the western side of the Sierra Vista subwatershed of the Upper San Pedro River Basin (Figure 2). Approximately 3 miles separate the upstream and middle sensors, and approximately 5.5 miles separate the middle and downstream sensors. Nearly half of the flows were recorded at more than one site, and three of the flows, including those resulting from the synoptic scale weather system of April 2001, were recorded at all three sites. More flows were recorded at the upstream and middle sites than at the downstream site. The upstream and middle sites, however, are within the city of Sierra Vista. Hence, urban runoff may play a role in the large number of flows recorded at these two sites that are not recorded at the downstream site.

Table 2 also highlights a number of the difficulties encountered when using the temperature-drop – low-temperature inflection point technique to interpret stream flow. First, uninterpretable data such as occurred with the middle sensor between July 29, 2001 and August 17, 2001 are the result of the sensor being pulled up to the surface during a flow event. By anchoring the sensor at the desired depth, most such occurrences can be avoided.

Second, modest localized precipitation events at road crossings can result in flow indicated at a sensor installed downstream from the crossing. Because such events represent small magnitude street drainage rather than large magnitude flow events, they give an inaccurate representation of what is occurring along the entire wash. This is the case with the middle sensor, and the two flows recorded at only that site may have been the result of localized urban drainage rather than true wash flow. This problem is resolved by moving the sensor upstream from the road.

Burial depth, which affects the mean amplitude of the thermograph, is a third factor that can affect flow interpretation. Although the control data from Greenbush Draw are for a sensor buried 30 to 33 centimeters below the streambed surface, most of the sensors throughout the subwatershed have been buried shallower than this. As a result, the mean amplitude of the thermal wave in most subbasin thermographs is commonly greater than at the Greenbush Draw research site, and a larger temperature-drop threshold is required when screening data to minimize the number of false positives. A series of sensors buried at multiple depths downstream from the Greenbush Draw gaging station have recently been installed for the purpose of quantitatively determining the optimum temperature-drop thresholds for various sensor depths and mean amplitudes.

Conclusion

Constantz et al. (2001), Lawler (2002), and Blasch et al. (2002) have demonstrated that temperature can be used to estimate the occurrence and timing of ephemeral and intermittent flow events. The temperature-drop – low-temperature inflection point method offers a simpler method of ephemeral streamflow analysis than does the standard deviation method. It requires fewer parameters (two: a temperature drop that exceeds a threshold value, and a following low-temperature inflection point) and fewer and less complicated computations (subtraction to determine flow duration) than does the moving standard deviation window method (five parameters; determination of various thresholds and filters, approximation of the thermal and hydraulic parameters for the site, and the calculation of the moving standard deviation). It is not clear at this time, however, how the two methods compare in detecting the onset and cessation of flow.

In addition, it is unlikely that the temperature-drop – low-temperature inflection point method can be used to indicate the onset of long term flows that are not the result of a significant precipitation event (e.g., Lawler 2002), nor the cessation of flows that last for more than 24 hours. Combining this method with the visual inspection method may prove effective for instances of longer term flow (more than 24 hours) in ephemeral channels. Also, the temperature-drop – low-temperature inflection point method does not appear to be effective in separating discrete flows that occur in rapid succession (within approximately 24 hours or less) on the basis of the Greenbush Draw data. In situations where sensors can be easily installed at the necessary depths for optimization, the moving standard deviation method of Blasch et al. (2002), optimized to detect all flows with no false detections, may be effective in combination with this method.

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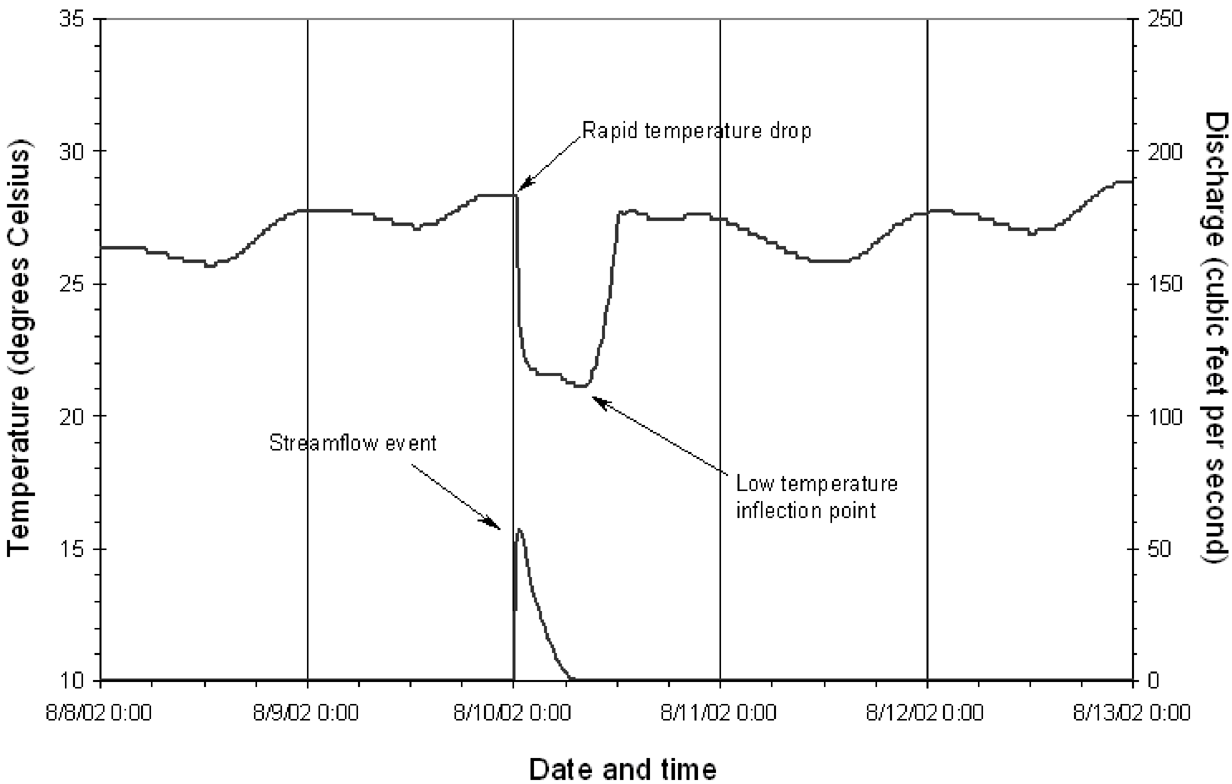

Figure 1. Greenbush Draw thermograph and streamflow-gaging station discharge record for 5 days in August 2002. The temperature sensor was 10 meters downstream from the streamflow-gaging station and buried 30–33 centimeters below the streambed surface.

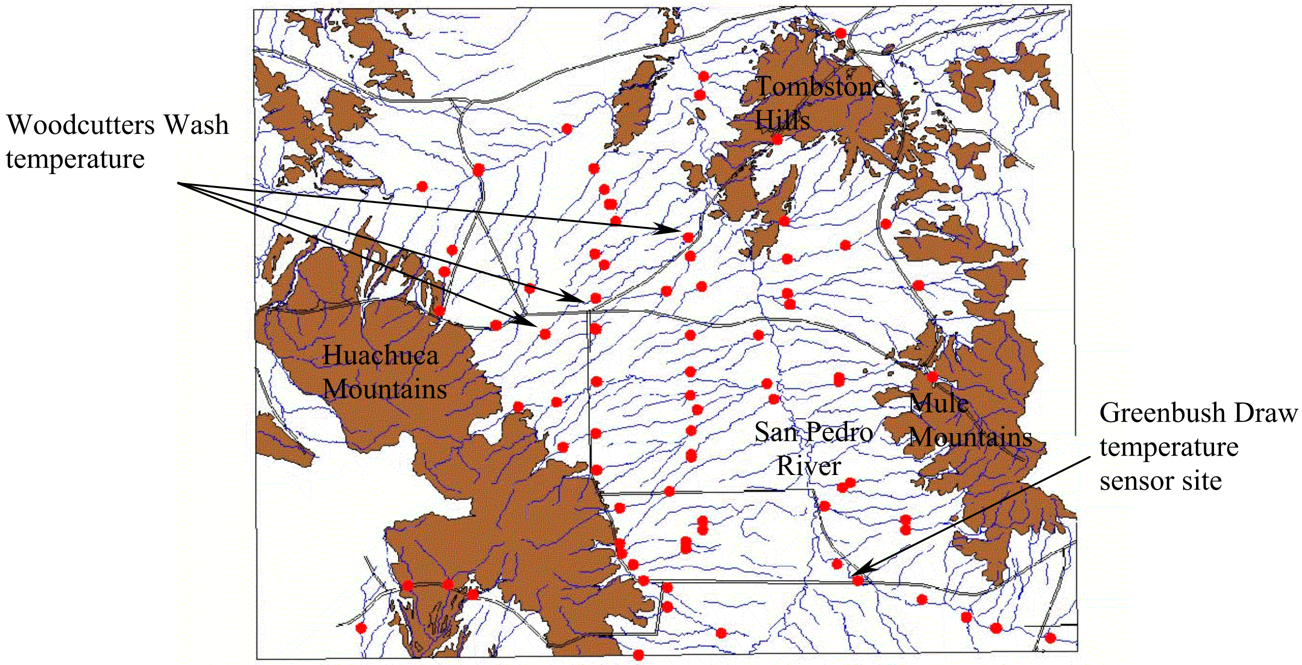

Figure 2: Sierra Vista subwatershed of the Upper San Pedro River Basin. Dots are location of temperature sensors.

Table 1. Temperature sensor flow detection at Greenbush Draw for various temperature drop thresholds compared to flow detection at Greenbush Draw gaging station. The temperature sensor is 10 meters downstream from the gaging station and 30-33 centimeters below the streambed surface. Values in bold are for the optimal temperature-drop threshold for flow detection (correct flow detection is maximized, whereas false negative and false positive flow detection and the time between predicted and actual flow onset and cessation are minimized).

Temperature drop threshold (^{o}C)		0.20	**0.25**	**0.30**	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
Flows correctly identified	N:	11	**11**	**11**	9	8	8	8	7	7	7	7	6	6	6	6	6	6
(of 13 possible)	Percent:	85	**85**	**85**	69	62	62	62	54	54	54	54	46	46	46	46	46	46
False negative flow identification (flows missed / total actual flows)	Percent:	15	**15**	**15**	31	38	38	38	46	46	46	46	54	54	54	54	54	54
False positive flow identification (false flow identifications / total flows identified)	Percent:	69	**8**	**8**	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Time of flow onset minus time of temperature drop (minutes)	Mean:	37	**37**	**37**	33	6	6	2	-4	-4	-4	-4	-7	-7	-12	-15	-15	-15
	Standard Deviation:	110	**110**	**110**	78	40	40	44	45	45	45	45	48	48	46	44	44	44
Time of flow cessation minus time of low-temperature inflection point (minutes)	Mean:	4	**4**	**4**	2	-34	-34	-34	11	11	11	10.7	-32	-32	-32	-32	-32	-32
	Standard Deviation:	232	**232**	**232**	251	243	243	243	224	224	224	224	212	212	212	212	212	212
Duration of flow minus time from temperature drop to low temperature inflection point (minutes)	Mean:	-33	**-33**	**-33**	-32	-39	-39	-36	15	15	15	15	-25	-25	-20	-18	-18	-18
	Standard Deviation:	231	**231**	**231**	204	222	222	220	185	185	185	185	166	166	170	169	169	169

Table 2. Flows interpreted using temperature sensors at three locations along Woodcutters Wash, upstream (left) to downstream (right). The reach covers approximately 13.5 kilometers (8.5 miles). Flows recorded at more than one sensor site are in bold. [MST, Mountain Standard Time; cm, centimeters; ^{o}C, degrees Celsius]

Woodcutters at 7th Street (upstream sensor) TidbiT serial number: 375010				**Woodcutters at Rt. 90 (middle sensor) TidbiT serial Number: 377793**				**Woodcutters at Moson Road (downstream sensor) TidbiT serial number: 377788**			
	Date and time of flow onset (MST)	Date and time of flow cessation (MST)	Flow duration (minutes)		Date and time of flow onset (MST)	Date and time of flow cessation (MST)	Flow duration (minutes)		Date and time of flow onset (MST)	Date and time of flow cessation (MST)	Flow duration (minutes)
1	**4/6/01 1:18**	**4/6/01 1:48**	**30**	**1**	**4/5/01 22:20**	**4/6/01 10:50**	**750**	**1**	**4/6/01 4:47**	**4/6/01 7:47**	**180**
2	**6/19/01 18:48**	**6/20/01 9:18**	**870**	**2**	**6/19/01 20:20**	**6/20/01 7:50**	**690**				
				3	6/25/01 13:30	6/25/01 15:30	120				
								4	6/26/01 11:00	6/26/01 16:45	345
				5	**7/7/01 13:30**	**7/7/01 14:45**	**75**	**5**	**7/7/01 14:15**	**7/7/01 14:30**	**15**
				6	7/9/01 18:45	7/9/01 20:15	90				
								7	7/16/01 15:30	7/16/01 15:45	15
8	**7/24/01 21:18**	**7/25/01 1:18**	**240**	**8**	**7/24/01 21:00**	**7/25/01 8:45**	**705**				
9	7/25/01 18:48	7/26/01 0:18	330								
10	**7/28/01 16:48**	**7/29/01 5:18**	**750**	**10**	**7/28/01 23:00**	**7/29/01 6:15**	**435**	**10**	**7/28/01 17:15**	**7/28/01 17:30**	**15**
11	8/5/01 18:48	8/5/01 20:48	120	*	NA 7/29/01 - 8/17/01 uninterpretable						
12	8/11/01 20:48	8/12/01 3:48	420	*	NA						
13	**8/13/01 19:18**	**8/14/01 1:48**	**390**	*	**NA**			**13**	**8/13/01 19:00**	**8/14/01 8:45**	**825**
14	8/16/01 19:48	8/16/01 21:18	90	*	NA						
15	8/17/01 20:18	8/18/01 4:18	480	*	NA			15	8/17/01 21:00	8/18/01 1:15	255
16	8/29/01 17:48	8/29/01 23:18	330	16	8/29/01 18:30	8/30/01 8:00	810	16	8/29/01 20:00	8/30/01 7:15	675
	Burial depth: 20 - 36 cm				Burial depth: 20 cm				Burial depth: 15-20 cm		
	Temperature drop threshold: 0.5 ^{o}C				Temperature drop threshold: 0.6 ^{o}C				Temperature drop threshold: 0.6 ^{o}C		